INVESTIGATIVE METHODS IN SPACE BIOLOGY AND MEDICINE. TRANSMISSION OF MEDICAL DATA

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INTRODUCTION

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One of the significant distinctions of space biology and medicine
is that to collect the necessary scientific information, to provide medical
monitoring during flight, and to solve diagnostic and prognostic problems
they must use telemetry methods. For the first time, physiologists
encountered, in cosmonautics, the need for strict conformity between the
volume of information transmitted and the carrying capacity of telemetry
channels, to design data measuring systems, and to program their operation.
The choice of investigative methods best suitable for medical monitoring of
man in space, appropriate modification of the chosen methodological proced-
ures, and extraction of maximum information about the physiological systems
of the organism obtained in space experiments have acquired the greatest
importance.

Biomedical information was first transmitted from a spacecraft to
earth during the flight of the dog, Layka, in the second Soviet earth
satellite. Thereafter, a wide spectrum of physiological methods of examin-
ing and monitoring the organism during space flight was tested in orbital
physiological laboratories, the second and third Soviet spacecraft. On
this basis, a system of remote medical monitoring was developed for the
first cosmonaut, Yu.A. Gagarin.

The Mercury program laid the foundation for subsequent comprehensive
biological measurements in manned orbital flights.

Development of cosmonautics is posing new and increasingly complex
problems to physicians and biologists. There is no other area of knowledge
with the dynamic goals, means, and results, and the close link between
practical requirements and development of scientific research that prevail
in sciences pertaining to investigation and conquest of cosmic space [76, 48,
49]. Here, investigative methods, and specifically the methods of obtaining
information about reactions of the living organism to the set of space
flight factors, play a role of utmost importance. The longer and more distant
flights make it imperative to work out problems of forecasting the physical

condition of cosmonauts, develop new approaches to monitoring the activities of crew members, on the basis of the conception of the spacecraft as a totally autonomous system [99]. For this reason, at the present stage of development of space biology and medicine, automation of physiological and medical readings is a pressing issue.

I. PHYSIOLOGICAL MEASUREMENT SYSTEMS IN SPACE RESEARCH

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During space flights, information about the condition of a cosmonaut reaches earth via three channels: radiotelemetry, television, and radio communication. Radiotelemetry is the principal method of transmitting physiological parameters recorded in the form of oscillograms. Television monitoring permits examination of motor activity, posture, facial expression of the cosmonaut, his behavior and activities. The study of radio conversations permits evaluation of verbal activity of the cosmonaut, adequacy of his answers, accuracy of reports, and intellectual level. For this reason, all of the flight data, including radiotelemetry, television, and radio dialogue data, must be analyzed for comprehensive assessment of the cosmonaut's condition.

The set of devices that permit physiological readings on a spacecraft includes sensors and electrodes, physiological radioelectronic equipment, instruments for accumulating and processing data, devices for transmission of information from the spacecraft to earth, and, finally, ground-based equipment: receiving, decoding, recording, etc. This entire set could be called a "physiological measuring system" [7].

The system of data gathering is the first element in the physiological measuring system. It is designed to convert physiological parameters into electric signals, or to derive bioelectric potentials. Sensors or electrodes are distinguished for these two objectives. Development of sensors and electrodes for use in space flight presents some difficulties. The sensor must operate for a long, continuous time, its operating characteristics must be stable during and after exposure to vibrations, accelerations, and various atmospheric factors (increased temperature and humidity, decreased barometric pressure); also, because it cannot be replaced in case of malfunction, it is imperative to constantly search for new methods of recording physiological reactions, to design better types of sensors, and to pay serious attention to placement of sensors on the subject's body. While the inconvenience of some examinations is brief on earth, during flight it becomes a continuous factor. Sensors and electrodes should not hamper

the cosmonaut in his work or elicit development of discomfort. This applies equally to animals, since discomfort elicits restlessness in the latter, increased motor activity, and this cannot help but affect the results of physiological examinations.

The placement of sensors and electrodes on the object under study (man or animal) constitutes a special problem. Most sensors and electrodes must be applied to specific points, and any minor shift could elicit substantial distortion of the tracings. In studies on animals, a solution to this difficult problem was found by implanting the electrodes under the skin or in the muscle, using special surgical interventions to assure exact placement of the sensor (for example, bringing out the dog's carotid to a skin flap to measure arterial pressure), or even implanting sensors in the animal's chest cavity. It is a considerably more complex matter to position and immobilize sensors and electrodes on the human body. At the present time there are many suggestions pertaining to pasting electrodes and sensors on the skin, sewing them into clothing, inserting them in the physiological orifices (rectum, nose, mouth) and even imbedding them under the skin. In the following, different types of sensors and methods of immobilizing them are described.

The equipment for recording physiological data on board a spacecraft presents several substantial differences, as compared to that used on earth. These differences are related, on the one hand, to the weight, size, and electric energy restrictions, and, on the other hand, to the specific conditions under which the equipment has to operate. The feasibility of recording specific indices in flight is determined by the characteristics of the measuring channels. These characteristics must conform with the physiological characteristics of the information for which a specific channel is intended. To determine the quantity of information, we must know the total number of signals possible under these conditions and the probability of appearance of each of them. To simplify the matter, we shall consider all signals equally probable. As the unit of measurement of quantity of information, the unit choice of two equally probable states is taken. Information (H) is measured in binary units per second (bits), according to the following formula:

$$H = n \cdot \log_2 m$$

where H is the quantity of information in bits/second; n is the rate of transmission, and m is the number of equally probable possible states.

The quantization rate or quantity of points transmitted per unit time must be twice the maximum signal frequency (Kotel'nikov [sampling] theorem) for undistorted transmission of the signal over a radio channel. This thesis is one of the most important in communications theory, and as applied to physiological data, it permits determination of the quantization rate required for undistorted transmission via a radio channel (see Table 1).

Each radiotelemetry channel is designed to transmit a specific quantity of information. The channel carrying capacity is also determined in binary

digits per second. The ratio of quantity of information that can still be transmitted over the channel without distortion to the channel capacity is called the coefficient of useful radio channel operation. The smaller the channel capacity, the higher the coefficient of useful operation.

Table 1. Tentative estimates of productivity of sources of physiological information and carrying capacity of radiotelemetry channels that transmit such information

Physiolog. parameter	Permissible top limit of frequency spectrum (hertz)	Accuracy of level quantization(%)	Number of discrete readings referable to time	amplitude	Quantity of data (bits/sec)	Required carrying capacity (bits/sec)
EKG	50	5	100	16	400	500-600
EEG	100	5	200	16	800	900-1,000
EMG	500	20	1,000	8	3,000	3,500-4,000
Pneumogram	4	25	8	4	16	20-25
Thermogram	0.005	0.5	0.1	256	0.1	0.1-0.2

The choice of methods of examining man and animals on spacecraft and satellites is closely related to problems of picking up and transmitting biological data. There are broader opportunities for using diverse methods in flight experiments with animals. For this reason, such experiments furnish not only scientific information but also evaluation of the informativeness of different methods in order to then transfer them to manned spacecraft. Since the time the second Soviet satellite was launched, with the dog, Layka, there has been a revolution in medical instrument making. Many medicophysiological measurements which are now routine both on earth and in space became feasible exclusively through the application of technological advances to instrument making, originating in space research. However, more and more often, there are significant restrictions to the use of some important methods during flight. More recently, there is more distinct emergence of medicophysiological systems to solve research problems and for medical monitoring [25]. Secondary use of some monitoring systems for investigative purposes [118] is growing important.

Table 2 submits some brief information about monitoring and examination methods, distinctions of picking up and transmitting biotelemetry data, and some of the principles involved in installing physiological measurement systems on Soviet and American spacecraft and satellites. We can distinguish three directions in development of physiological methods in cosmonautics:
1) search for methods, development and testing of systems of medical monitoring of cosmonauts in flight (second to fifth Soviet Vostok space satellites, Mercury, Apollo);
2) development of systems of automated physiological experimentation in space (Kosmos 110, Biosatellite 3);
3) development of systems of medicophysiological examination of the human organism in space (Voskhod, Gemini, Salute 1).

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Table 2. Biomedical information pick-up and transmission on board space-
craft and satellites

Spacecraft and satellites	Year of launch	Physiological measurement methods	Distinctions of on-board med.equip. & biotelemetry systems	Reference
2nd Soviet earth satellite	1957	Electrocardiography, pneumography, arterial oscillography, actography	Equipment was turned on with a program device	18
2nd-5th Soviet spacraft-satellites	1960-1961	EKG, pneumography, phono-cardiography, sphygmo-graphy, electromyography, actography, arterial oscillography, body temp-erature reading, seismocardiography	Commutator for successive measurement of slowly changing parameters, electrocardiophone	2,4
Vostok spacecraft	1961-1963	EKG, pneumography, seismo-cardiography, kinetocar-diography, electroocu-lography, EEG, galvanic skin reflex	Placement of preamplifiers in cosmonauts' clothing; multipurpose use of amplifier channels	2, 4, 10, 44, 45
Mercury capsules	1962-1965	EKG, pneumography, arterial pressure and body temp. readings	Automatic art.press. reading, system of EKG and impedance PG tracing using common electrodes	104, 109, 120
Voskhod spacecraft	1964-1965	EKG, PG, seismocardio-graphy, EEG, electro-dynamography, motor acts of writing	Distinction of two units: medical monitoring and medical examinations; special med.monitoring panel upon going into orbit	24, 15
Soyuz spacecraft	1967-1971	EKG, PG, seismocardio-graphy, body temp.	Special medical monitor panel for recording body temp. and pulse while going into orbit [space]	32, 41
Gemini spacecraft	1966 1967	EKG, impedance PG, art. press. and body temp., phonocardiography, EEG	Use of special on-board tape recorder for medico-physiological parameters	86, 92, 65
Cosmos 110, artificial earth satellite	1966	EKG, sphygmogram, seismo-cardiogram, aortic press.	Electric stimulation of receptor zones of carotid sinus using a program device; automatic adminis-tration of pharmacological agents	47

Table 2, continued

Apollo spacecraft	1968–1972	EKG, impedance PG	Upon exit on the moon's surface pulse rate was retranslated in the lunar module and through its telemetry system to earth	75, 77, 92
Biosatellite 3	1969	EKG, impedance PG, EEG, changes in blood press. by cathetrization of pulmonary vessels, arterial and venous system, brain temp. with implanted sensors, study of behavioral reactions	Automatic analyzer of calcium, creatine, and creatinine in urine; special biotelemetry device with 10 channels operating at an access speed of 100/sec and one "slow" channel (10/sec)	63
Salute orbital station	1971	EKG, PG, seismocardio-graphy, kinetocardiogr., sphygmogr. of femoral artery, arterial press. by tachooscillographic method	On-board tape recorder to record investigative information; special unit of investigative [research] equipment	

Figures 1, 2, and 3 illustrate block diagrams of the biotelemetry systems of Vostok 3, Voskhod 1, and the artificial satellite, Biosatellite 3, as examples of the construction of physiological measurement systems. Of course, in manned flights, especially at the early stages, attention was focused on medical monitoring. The development and testing of research equipment was of secondary significance until recently. However, with the increase in duration of flights, prognostic information is growing increasingly necessary. To obtain such information the following are required: broader program of physiological measurements and, especially, in-depth mathematical analysis of the data obtained and addition of the necessary functional tests.

II. METHODS OF CLINICOPHYSIOLOGICAL EXAMINATION IN FLIGHT

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1. Methods of Examining the Circulatory System

a) <u>Electrocardiography</u>. To record the EKG in the course of space flight it was necessary to develop, in essence, a new technique, whose distinctive features were: lack of interference when the cosmonauts moved while performing their flight assignments; lack of skin irritation or discomfort in the case of studies taking up many days; adequate diagnostic value of the tracings obtained; lack of distortions on tracings in the course of conversion and transmission to earth.

All this made it necessary to conduct special research to develop electrodes, select placement points for them, and find means of providing long-term immobilization [1, 30].

The chief prerequisites for surface electrodes used in long-term monitoring are: 1) reliable mechanical attachment, 2) reliable electric contact [19]. The following factors present additional difficulties in this problem: presence of contact potentials between the surface of a metal electrode and the electrolyte it is dipped in, the need to reduce resistance between the electrode and skin and increase in total input resistance of amplifier. Ideally, the input amplifier resistance should be infinite, and that of the electrode system very low. Then the change in resistances occurring in the "electrode -- skin" system with body movement would not affect the potentials at the amplifier input generated by the contact potential battery. The amplifier should serve, in relation to the electrode system, as an electrostatic measuring instrument that does not pick up any current from other tissular generators or electrode-electrolyte batteries.

The progress in the field of development of electrodes can be illustrated on the example of the programs of the Mercury, Gemini, and Apollo. The liquid electrode developed for the Mercury project consisted of a silicone rubber ring that supported a disk-screen of stainless steel with 40 holes (see Figure 4, A). After placing the electrode in the space

between the steel disk and the skin, electrolyte was added. However, these electrodes produced much interference in flight when the cosmonaut moved [95], probably due to polarization. For this reason, in the Gemini flights the design of the electrodes was perfected. A disk of pure silver was used and anodized [80]. The EKG electrodes for the Apollo flights differed in that a hard plastic cap was used for placement of silver-silver chloride electrodes.

A decrease in interelectrode resistance is important to assure prolonged interference-free EKG recording. For this purpose, different pastes and methods of treating the skin are used (soap cream, fine-ground pumice, or mixture of alcohol and ether). For the Mercury program, a paste was developed that did not irritate the skin for 48 hours. In its latest modifications, 0.1% propyl-p-hydroxybenzoate was added as an antibacterial agent. The paste method was used to immobilize the electrodes on the skin (during the flight of Yu.A. Gagarin and all American flights) or else they were taped on.

During the flight of G.S. Titov, the electrodes were pasted on (in the MX lead) and taped -- in the DS lead [1, 44]. Subsequently, a complete change to the tape system was made on Soviet spacecraft. This system includes a chest belt with built-in silver electrodes, 18-20 mm in diameter, with grooves for the paste, and two straps crossing over the cosmonaut's chest and attached on his back. There are rubber segments in the belt that help provide good contact between the electrodes and the skin.

As a result of experimental research, two bipolar chest leads, named MX and DS [44] were chosen for the Vostok spacecraft. The advantages of these leads are: very interference-free (minimum level of muscular biopotentials); convenient attachment of electrodes; high diagnostic effectiveness. In the MX derivation, the electrodes are placed on the midline of the chest at the level of the manubrium and xiphoid process, and the DS lead is along the mid-axillary line on the right and left, at the level of the fifth intercostal space. Thus MX is referable to the sternal group and DS to the axillary group of leads, according to J. Roman [111, 112].

The system of placement of electrodes in the Mercury project consisted of three electrodes for two EKG leads. Subsequently a four-electrode system was developed (... [omitted] and MX). In the Gemini flights, the DS electrodes were also used to record the impedance pneumogram (see Figure 4, 5).

No doubt, the search for convenient electrodes and placement points for electrocardiography during space flights should be continued. We could, for example, mention a very promising electrode model proposed in the GDR [119]. Three disks, 20-30 mm in diameter, are placed 5-10 mm apart on an insulating plate. The extreme disks are active, and the middle one ("earth") serves to diminish induction [?].

Of great interest are the "spray-on" electrodes proposed by J. Roman [111]. Such electrodes consist of metal and cement dust which, along with solvent, is applied to the skin using a special sprayer. The sprayed on electrode is about 1 mm thick and 19 mm in diameter. S fine wire is used to derive biopotentials. The mean interelectrode resistance is about 70 kohms.

Richardson et al. [110] propose the following three types of electrodes to record electrocardiograms for 30 or more days.

1. Electrodes with lithium chloride used without paste and mounted on a belt system. Interelectrode resistance is about 15 kohms. An amplifier with a range of 2-50 hertz and input resistance of the order of 1,000 megohms is used.

2. Subcutaneous electrodes. Stainless steel and tantalum wire clips, 6 mm long, were used. As early as 3 days after implantation, discomfort disappears. Interelectrode resistance reaches 50 kohms.

3. Insulated electrodes consist of aluminum disks covered with a thin insulating layer. Resistance between the skin and electrode is over 30,000 megohms. A special circuit is used on a field-effect transistor in a grounded screen connected to the electrode.

To improve the quality of EKG recording, some authors propose the use of an amplifier with limited frequency band. J. Roman [112] indicates that restriction of the band to 100 hertz at the top does not influence the clinical informativeness of the tracing, at up to 50 hertz it virtually does not change the EKG, at up to 25 hertz it causes some distortion. Bottom limitation to 0.2 hertz does not alter clinical informativeness. The effect of muscular interference as related to different ranges of amplifier band was investigated by A. Freiman et al. [82]. Optimum solutions were obtained for a channel with interference, where maximum signal/noise ratio was created by changing the frequency scale.

b) Phonocardiography. As we know, the value of phonocardiography in a cardiological examination is that it permits objective registration of the volume of sounds, their phase correlations, and a number of variable characteristics of the cardiac cycle. In view of the fact that cosmonauts are a specially screened and trained group of individuals without patholo- gical heart murmurs, it is purposeful to concentrate on recording heart sounds. A special method was developed, which was named "integral phono- cardiography" [16]. It consists of picking up the low-frequency envelope of audio frequencies by detection and integration of the output signals of the phonocardiographic amplifier. Radiotelemetry channels with considerably smaller capacity can be used to transmit the "integral" curve than for transmission of an ordinary phonocardiogram. The method of "integral" phonocardiography was used in flight experiments with animals on the second and third Soviet satellites.

Phonocardiography was used by American researchers in the flight of Gemini 4 [122]. Phonocardiograms were recorded on both crew members using miniature microphones weighing 7 grams, attached to the chest with special paste. A preamplifier was installed in the space suit. Phonocardiograms were taken on board on a magnetic recorder, then rerecorded and the data analyzed on earth.

c) <u>Seismocardiography</u>. The electric and sonic phenomena associated with cardiac contractions do not furnish information about the ultimate results of cardiac activity, the force, rhythm, and rate of ejection of blood from the ventricles into the large arterial trunks, or how the heart fills during diastole. One of the methods that investigates these aspects is ballistocardiography, however, it is practically impossible to use its clinical variants in space flight. For this reason, a special modification of ballistocardiography was developed and named seismocardiography [10]. In essence this involves registration of the third and fourth derivations of the dorsoventral (or longitudinal) ballistocardiogram. The principle of sensor operation is based on translation of pulse movements of the chest wall into oscillations of an inert (seismic) mass resiliently connected to the object being measured. The first pickups were tested in flight experiments with animals.

The seismocardiographic complex consists of two distinct parts (cycles): systolic and diastolic (see Figure 5). The amplitude of each cycle is directly related to the magnitude of cardiac contraction in a given phase. The extinction time is related to the time relations between these forces. In view of the fact that the frequency of oscillations of the seismic mass proper is rather high, respiratory excursions and other slow body movements have virtually no effect on the tracing; there are merely some respiratory variations of amplitude on the tracing. As a rule, good tracings are obtained only when the subject is at complete rest.

The SKG sensor was first used in tests on humans during the flight of Vostok 5 and Vostok 6 [10].

The seismograms were recorded on the same telemetry channel as the electrooculogram. This was found feasible in view of the different frequency spectra of the processes. Subsequently, on the Voskhod and Soyuz spacecraft, seismocardiography became one of the methods of continuous medical monitoring.

d) <u>Kinetocardiography</u>. During the flight of G.S. Titov, to record the kinetocardiogram, a sensor in the form of a miniature microphone with a one-transistor preamplifier [2] was used. The tracing obtained, the kinetocardiogram, characterizes local vibrations of the chest wall and permits evaluation of the phases of the cardiac cycle and coordination of right and left heart contractions. The pickup is placed in the region of the apical pulse and attached to the inner surface of the chest strap. Vibration of the chest wall was recorded in the frequency range of 10-20 hertz. The flaws of the electromagnetic pickup are its low sensitivity and

impossibility of picking up vibrations in the range of frequencies of the order of 1-5 hertz. For this reason, efforts were subsequently made to develop kinetocardiographic pickups on the basis of piezo elements [9].

e) Measurement of arterial pressure. As we know, the methods of measuring arterial pressure are divided into direct and indirect. Direct methods were used in the flight experiments with animals (Cosmos 110 and Biosputnik 3). A system with pulsating delivery (heparin) was installed on Biosputnik 3 to improve patency of implanted catheters. Four catheters (two venous and two arterial) made it possible to obtain reliable information about dynamics of blood pressure. Sensors, in the form of ordinary electric bridges, were used; one of the arms changed its parameters depending on pressure on the sensor diaphragm.

To record arterial pressure of cosmonauts, indirect methods were used: oscillography (USSR) and audio (USA). Arterial oscillography is based on recording pressure fluctuations in a cuff depressing a vessel. Tacho-oscillography (method of N.N. Savitskiy [54]) records the velocity component of oscillations. The audio method is based on recording sonic phenomena (Korotkoff sounds) at the site of vascular ligation using a microphone.

The oscillatory method was first tested during the flight of Layka. It was then used in experiments on the second and third Soviet spacecraft-satellites. A compressor cuff placed on the carotid exposed in a skin flap was used to measure the animals' arterial pressure. Since the cuff is small (about 3 sq cm), a plunger type automatic device was used to create pressure in it. This device consists of a metal cylinder with thoroughly ground plunger. The size of the cylinder is such that a pressure of up to 220 mm Hg is created in the cuff with each stroke of the plunger. The pressure in the cuff changed linearly and was converted into tension by means of an electric micromanometer.

During the flight of Voskhod, B.B. Yegorov, cosmonaut-physician, took the arterial pressure readings on crew members. He used an ordinary tonometer, and maximum and minimum pressure was determined by auscultation of Korotkoff sounds.

In the Mercury and Gemini flights an automatic sphygmomonometric system was used involving the audio method of determining pressure [104]. In the first orbital flight of J. Glenn, there was no automatic pressure device, and the astronaut pumped air into the cuff with a bulb. An automatic pressure device was used in all subsequent flights. A pressure of 220 mm Hg was reached in 30 seconds. Special safety features were provided to lower the pressure in the event it held at more than 60 mm Hg for over 2 minutes. Cuff pressure dropped linearly from 220 to 60 mm Hg by means of a special pressure regulator. The microphone was in the lower part of the cuff, and this turned out to be the most effective from the standpoint of sensitivity and noise-proof quality of the measuring system (see Figure 4, B). The pressure curve and arterial phono-oscillogram were recorded using the same

telemetry clip. A miniature piezo microphone was developed, 3.5 cm in diameter and 0.5 cm thick. Its sensitivity to external interference was significantly diminished.

f) Sphygmography. Carotid sphygmograms were recorded on dogs during the third and fourth Soviet spacecraft-satellite flights. As a pickup, the casing of the cuff for carotid pressure measurement was used. Instead of the rubber cuff, a tenzolit [taeniolite?] element (tube with coal dust) or a piezocrystal was used. A voltage divider circuit was assembled for the tenzolit pickup. The dividing capacitance with the RC chain [circuit] form the simplest low-frequency filter limiting the frequency band and thus lowering the interference level. Due to the solid contact between the pickup element of the sensor and vessel, the cuff sphygmographic pickups produce very stable tracings. Movement of the animals and even vibration have little effect on their quality.

g) Development of new methods of studying blood circulation in space flight. Apparently, electroplethysmography is one of the promising techniques in space cardiography; it is known in two variants: rheography, developed in 1945 by Poltzer, Marco, and Holtzer [106], and dielectrography [72], created by Atzler and Leman (1932). In both cases, the readings are based on use of high frequencies, but with rheography primarily the changes in ohmic component of complex resistance of living tissues are examined, and with dielectrography the capacitance component.

For man, electroplethysmography is probably the only method, acceptable in space flight, of studying blood supply to the brain. Work in the field of intracranial electroplethysmography (rheoencephalography) resulted in development of radiotelemetry systems to study blood supply to the brain [38]. More recently, a phase-sensitive circular detector has been used, which removed the chief disadvantage of rheoencephalography, nonlinearity of voltohmic characteristics near the balance point of the bridge [38].

Diagnostic importance is attributed to thoracic and abdominal rheography [7]. A method of chest rheography has been developed using additional electrodes inserted in the cosmonaut's chest strap. Recording the rheogram of the pulmonary artery appears purposeful.

In spite of the definite practical value of rheography to examine central and peripheral circulation, the need for continuous contact between the electrodes and skin limits the area and duration of application of this technique. For this reason, attention was concentrated on investigation of contact-free techniques, and in particular dielectrocardiography. Two types of instruments have been developed [57]. The first is based on the measurement principle proposed by Atzler and Leman [72]. The generator operating frequency is 8 mhertz. The outlet ["suction"] "secondary circuit" is inductively connected to the generator circuit, and the patient's capacitance is connected to it. Changes in amplitude of generator oscillations due to changes in quality of the primary circuit are recorded. The changes in active

resistance of the secondary circuit affects this quality more than changes in capacity. Thus, this system makes records primarily of changes in active losses in the pickup-condenser, rather than changes in the dielectric constant. To record the true dielectrocardiogram, an instrument was developed, based on the principle of frequency modulation with a sensitivity of 1 mv/ 0.001 millifarad, with recording on any electrocardiograph. Figure 5 illustrates a dielectrogram tracing in the region of the fifth intercostal space along the anterior axillary line. The fact that the electrodes can be placed in the clothing, without contact with the skin, makes this a promising technique for wide use in prolonged space flights for both medical monitoring and research purposes.

Vibrocardiography is a promising technique to study cardiodynamics. This method was developed by Agress et al. [69, 70] and is a variant of ballistocardiography and low-frequency phonocardiography. A sensitive piezo-microphone and amplifier system with a frequency band of 2-2,000 hertz are used. Vibrations are recorded from a point in the fourth intercostal space, 2 cm to the left of the sternum. A 1-2 cm shift of the microphone does not affect the shape of the tracings. Ferruginous ointments are used to eliminate friction between the pickup and the skin. The polarity of the tracings was maintained so that movements of the chest wall toward the outside were reflected in the form of positive deflections. The vibrocardiogram is described by the same indices as the ballistocardiogram waves (see Figure 5). H corresponds to the start of isometric contraction, L_2 -- opening of the semilunar valves, L_2 [sic] -- closure of semilunar valves. A formula has been proposed for indirect estimation of the stroke volume from the vibrocardiogram [69]. This formula was derived on the basis of comparison of the vibrocardiogram data to the results of estimation of minute volume by the dye dilution method (coefficient of correlation: 0.90).

In order to obtain information about the cardiac cycle phases, a method of perimetric cardiography (PCG) was developed; it is based on recording microfluctuations in the perimeter of the chest by means of a pickup installed in the chest strap [14]. In a simplified variant of this technique, a carbon respiration pickup was used (resistance: 1.5-3.0 kohms), as well as a differentiating RC circuit [chain], and electrocardiographic amplifier. The PCG is recorded during breath holding. The structure of the curve corresponds to that of the acceleration kinetocardiogram (see Figure 5).

Ultrasonic Doppler cardiography [23] is promising for use in long space flights. This technique is based on recording reflected ultrasonic oscillations whose frequency is distinct from the transmitter frequency, and the faster the object moves, the greater this distinction (Doppler effect). Furthermore, the frequency amplitude characteristics of the reflected signal depend on the acoustic properties of the medium and changes in tissue density at different phases of the cardiac cycle. To obtain information about the phase structure of cardiac contractions, a "nonsearch" [?] method of ultrasonic Doppler cardiography was developed which permits examination of cardiac activity of man during physical activity. The quality of the tracing is as good as the EKG recorded in the Nebov leads.

The pickup is a piezo element, in the form of a cylinder, 12 mm in diameter and 6 mm in thickness. It is attached by means of an elastic belt in the region of the fourth-fifth left intercostal space. A system has also been developed and tested for wireless transmission of the ultrasonic Doppler cardiogram using a miniature radio transmitter worn by the subject [34].

Much attention is being given to development of methods of studying peripheral circulation. Work is in progress at the Stanford Research Center on a direct power method of measuring arterial pressure [108]. A transducer was created which measures arterial pressure according to movement of the skin surface above the artery. The artery is assumed to lie on a hard base with elastic walls and surrounded by homogeneous tissue. The mathematical model of the measurement system is based on the assumption that distended and constricted tissues can be represented as linear springs. The pickup is 1.5 mm wide and 6.5 mm long. At a pressure of 40 mm Hg it was necessary to measure a force of 5.5 grams, which, with deviation of up to 3 mm, elicited a deformation of 1.8 kg/cm. When the pickup was reduced, it was found to be sensitive to inertia of movement of the transducer itself as well as extremely thermosensitive. Further development of this technique resulted in a pickup to measure small forces with a shift close to zero, using a lever dynamometer system with feedback. A laboratory prototype of the instrument has been constructed with a Hall effect transformer. One of the main advantages of the direct power [energy] principle of measuring blood pressure is that ideal, absolute calibration is possible. The main problem is to place the transducer correctly on the artery.

Another method of indirect measurement of arterial pressure consists of using a pickup located on the ear, with cycline [cyclic?] squeezing of the helix [121]. This pickup consists of a corrugated ring and blood pulsation detector which measures the fluctuations in transparency of the capillary bed to infrared light. Control experiments showed that the technique is very accurate and presents no inconvenience to the patient.

Of particular interest is development of methods of studying vascular tonus. One of the valuable methods of studying peripheral circulation, including venous tonus, is the method of N.I. Arinchin [6]. It is based on recording the volumetric changes in the extremity with gradual elevation of pressure in a cuff worn proximal to the region examined. The degree of elevation of the plethysmographic curve serves as a measure of venous tonus. Step-by-step pressure elevation is a more accurate method.

2. Methods of Examining the External Respiration System

In the course of preparations for the flight experiments on the Vostok spacecraft, different variants of sensors were tested for pneumography, including some based on the piezoelectric effect, wire potentiometer, and tensiometric circuits. All were found unsuitable, either due to large size or the need to develop special amplifying and measuring circuits. From the standpoint of simplicity and economy, a carbon sensor was found to be the most suitable; it consists of a rubber tube filled with carbon (microphone)

powder. When it is not stretched, such a pickup has a resistance of 100-500 ohms. When stretched, the resistance increases to several thousand ohms. The sensitivity of the pickup can reach tens of ohms per mm of displacement. To measure respiration during space flight, the carbon sensor is attached in the chest belt in such a manner that it would be distended along with the rubber inserts during respiration.

Another type of sensor for pneumography has been named a contact sensor. It is based on opening and closing of an electric circuit by means of a microswitch controlled with a capron cable. The contact sensor operates whenever there is a change in direction of movement of the capron cable which is attached to the chest belt at the opposite end of the rubber insert. Square pulses are recorded, which correspond to inspiration and expiration. From the standpoint of reliability, the contact sensor is preferable to the carbon one, since its operation is not impaired when the initial tension of the belt is altered.

A special belt with tenzolit and contact pickups was used to record respiratory excursions of animals. Elastic inserts were sewn into the belt in such a manner that an increase in perimeter of the dog's chest in inspiration and decrease in expiration elicited extension or contraction of the rubber tube with carbon dust. The design of the belt included measures to standardize the tension of the tube by means of a special kinematic system.

Different methods were used to record respiration in the American space studies: pneumography (rubber tube with copper sulfate solution), pneumotachography (variant with heated thermistor attached in the form of microphone in the flow of exhaled air), and impedance pneumography (measurement of electric resistance of the chest). According to a number of authors, the respiratory changes in impedance with the electrodes in the sixth intercostal space, on the right and left, along the mid-clavicular line, are proportional to magnitude of pulmonary ventilation [93]. There are reports of a miniature impedance pneumograph to be placed in the astronaut's clothing [101]; the dimensions are 13×56×94 cm, and it weighs 125 grams.

To reduce the number of electrodes on the cosmonaut's body, special trap filters have been developed which permit using the same electrodes to record the EKG and impedance pneumogram. The filters are tuned to the frequency of the pneumograph generator and are connected to the input of the EKG amplifier [80, 84].

There are some advantages to the impedance pneumography method, as compared to other methods that do not use masks, in the sense of possibility of quantitative estimation of pulmonary ventilation, however, it is not suitable for lengthy studies. For this reason, the possibility of recording respiration by means of dielectrography merits attention. A miniature transistorized instrument has been developed which records the changes in value of the loss angle in the condenser, between the plates of which is a segment of the chest [56]. The generator has an operating frequency of

8 mhertz; one of the plates is mounted on the back of the chair, and the other is the "ground." Thus respiration is recorded without contacts. In view of development of a frequency method of recording the dielectro-cardiogram, efforts have been made to use it also for quantitative estimation of lung volumes. In this case, the electrodes, in the form of foil plates, are sewn into the subject's shirt.

3. Methods of Examining the Vestibular System

After vestibular and vestibulosensory disorders were discovered during the flight of G.S. Titov [44], in the physiological measurements were included examinations that would characterize the functional state of the vestibular system. A set of four special tests was developed, providing for alternate coordination and load tests [45, 25]. These tests consisted of evaluation of spatial orientation with the eyes closed and open, a series of head and body bends and finger-to-nose tests, determination of ability to perform fine coordinated acts (writing, drawing with eyes open and shut). To assess the different reflex changes due to vestibular stimuli, it was very important to make a complex evaluation of all the other parameters recorded: EKG, respiration, EEG. Electro-oculography was added to the telemetry program, starting with the flight of A.G. Nikolayev.

There are considerable methodological difficulties involved in performing electro-oculography in prolonged space flights. Thus, it is virtually impossible to use nonpolarizing electrodes. It is impossible to assure reliable contact between the electrodes and skin, when the former are placed in the above points, for a long period of time. For this reason, it was necessary to develop a method of recording electro-oculograms under specific conditions. In the first two flights, silver electrodes, mounted in plastic spring inserts firmly connected to the helmet, were used. The electrodes made close contact with the skin, in the region of the zygoma, near the external angles of both eyes. Eye movements to the right and left elicited both biopotentials related to eyeball movement and action potentials of facial and oculomotor muscles. The potential level was 50-100 microvolts. This made it necessary to use a preamplifier with an amplification coefficient of about 20. AC amplifiers were used, so that the electro-oculogram was recorded as the first derivative, i.e., a velocity curve [2].

Subsequently a method was developed to record the electro-oculograms using removable electrodes located in the immediate vicinity of the external angles of the eyes and connected to amplifiers by means of snaps on the helmet. This method furnishes better tracings, but requires preliminary instruction and training of the cosmonauts.

To study the sensitivity of the vestibular system, in addition to adequate stimuli, inadequate electric stimuli are also proposed [59]. Electric stimulation of the vestibular apparatus was used as a diagnostic test by the cosmonaut-physician, B.B. Yegorov, in the studies on Voskhod.

When examining the vestibular system, in addition to movements of the eyeballs, body and head movements are also taken into consideration.

Special sensors in the cosmonaut's helmet [29] can be used for objective
recording of such movements. Studies of head movements are important to
determine the accuracy of vestibular test performance, as well as to evaluate
reflex reactions to stimulation of the vestibular analyzer. Special tests
were performed in the Vostok flights, for the purpose of evaluating coordi-
nation of movements, including writing tests consisting of drawing various
geometric figures with the eyes open and shut. Analysis of different
autonomic reactions, pulse, and body temperature [40] is important in
assessing the condition of the vestibular system. There are investigations
showing the effect of vestibular stimuli on electric potentials of the
stomach [58]. Since vestibular disorders are associated with diverse
autonomic and coordination disorders, development of special tests for
automated examination of vestibular functions should proceed along the
lines of measured loads with recording and processing of parameters such as
rhythm of cardiac contractions, motor reactions, galvanic skin potentials.

4. Methods of Examining the Neuromuscular System

Investigation of man's efficiency [fitness for work] is of primary
importance in order to solve the practical problems of cosmonautics. Prob-
lems pertaining to guiding a spacecraft can be solved only on the basis
of optimum choice of data characteristics of the "man -- machine" system
with the necessary coordination of voluntary movements.

The information [data] links between the cosmonaut and spacecraft
systems are of both scientific and practical interest. It is important to
determine the effect of space flight factors on various information processes.
Thus, it is known that weightlessness is associated with a decreased flow
of afferent impulses. This circumstance aggravates hypodynamia and relative
isolation. Processing of information in the cosmonaut's central nervous
system and acts of realization of known motor skills can also change under
the unique conditions of space flight. The practical aspect of this problem
is ultimately related to the cosmonaut's ability for purposeful action and,
in particular, performance of processes involved in controlling the space-
craft.

The flights of Soviet and American cosmonauts indicated that man can
perform in space all of the complex operations involved in guiding the
spacecraft, preparing for docking, moving from one spacecraft to another
in space, performing assembly work, astrophysical observations, photography,
etc. However, operations take more time in space than on earth, and they
are more tiring [24].

The capacity for purposeful activity is closely related to the
condition of the nervous and muscular systems. The first investigations
of these systems were made already during the flight experiments with animals.
Actography and electromyography were used. Subsequently, the content of
radio conversations, television data, analysis of entries in the spacecraft
log, etc., were used to evaluate the activity of cosmonauts. Electroencephalo-
graphy (EEG) was an important method of studying the condition of the central
nervous system.

a) Actography. Motor activity in space flight can be studied by
the television data, as well as some artefacts of physiological tracings,
for example the EEG or seismocardiogram.

In order to study motor activity of animals, two types of pickups
were used. One consisted of a potentiometer controlled by a capron string
connected to the dog's clothing. Three such pickups, installed in differ-
ent parts of the cabin and recording the animal's movement along three
perpendicular axes, furnish information about the spatial position of the
animal and its motor reactions. However, this is not enough to investigate
the magnitude of exertion, so that a different type of pickup [29] was
proposed, built into the cables that attached the dog to the cabin floor.
These contact-potentiometric pickups were switched on only when the cable
was extended, and their resistance changed in proportion to the force applied.

Analysis of movements was made by comparing the actograms to the
television image. By virtue of combined evaluation of all the data, it was
possible to gain an idea about the animals' behavior in a weightless state.
Telemetric recording of actograms is also of some value to assess other
indices, since it demonstrates artefacts related to the animal's movements.

b) Dynamography. Work on a wrist dynamograph was chosen as a muscle
load, when developing tests for programmed medical examinations. Such a
load can be used whatever the space limitations, and with the appropriate
setting of rate and force of squeezing it is possible to obtain information
about the time and force relations in the act of movement coordination and
about the physical fitness of the cosmonaut.

An electrodynamograph was developed to record dynamograms. It has
a linear scale in the range up to 50 kg. Both the force and endurance, as
well as fatigability, can be examined with the electrodynamometer. Endurance
studies were made according to time of maintaining exertion equal to half
the maximum exertion, or by the ratio of force amplitude at the start to
the amplitude at the end of a set interval during which a close to maximum
exertion is maintained. Ergography was used to study fatigue. The subject
was given a rate and force to maintain (or these parameters were arbitrary),
then fitness was evaluated within a specific interval of time.

The dynamograph test was added to the flight program on the Voskhod
spacecraft. The problem consisted of squeezing a wrist electrodynamograph
[17] for 1 minute, rhythmically, with the same force and same duration.
All of the cosmonauts showed some changes in the dynamogram during flight.
Thus, even the first experience in using the dynamograph in flight was
successful; it demonstrated some of the distinctions in performance of
coordinated force acts in weightlessness.

c) Recording motor acts of writing. An effort was made, during
the flights of the Voskhod series of spacecraft, to evaluate movement
coordination in weightlessness, according to handwriting. For this purpose,
analysis was made of the cosmonauts' entries in the spacecraft logs (expert

handwriting analysis), and it was concluded that there are deviations in handwriting in a weightless state [39]. For this reason, a method was developed for objective recording of motor acts involved in writing, with telemetric transmission of data. A special induction type instrument was designed and added to the on-board equipment of Voskhod [7].

The device consists of two wooden (or plastic) platforms, securely connected with four flat, organic glass, spring elements. The trays [platforms] can move only in the direction perpendicular to the plane of the spring. There is a permanent magnet and induction coil in the device, which are attached to opposite platforms. If a sheet of paper is placed on the top tray of the instrument and some letter or digit is written down on it, the movement of the pencil is transmitted to the platform and causes it to move. As a result of this, induction current is generated in the coil, proportional to the rate of pencil movement and sine of angle formed by the direction of movement of the tray and direction of pencil movement. An ordinary EKG channel is used to record the signals. The data obtained during the flight of Voskhod revealed that with this device it is possible to demonstrate a number of deviations of coordination of movements while writing. Analysis of the oscillograms showed that there was an average 51% increase (when writing with eyes open) and 17% increase (with eyes closed) in time required to draw a double spiral. Impairment of movement stereotype was also observed. Motor skills involved in writing the number, 6, and in drawing were less impaired than more complex movements, and this can be attributed to the greater degree of automatization.

Subsequent development of techniques to record writing motor acts was related to attempts to objectivize some psychological tests [17] and to create new types of pickups [3, 7].

d) Electromyography. Experience in telemetric recording of electromyograms was gained during the flight of the third Soviet satellite-spacecraft. To transmit the relatively high-frequency signals of muscular biopotentials (up to 500 hertz) through the telemetry channels, "integral" electromyography was used; it consists of detection and integration of amplifier output signals. The method of "integral" electromyography furnishes data about EMG changes during movement and static loads which, combined with the actogram, could be used to describe the motor acts of animals in flight. The theoretical substantiation of "integral" electromyography ensues from the following theses. The EMG parameters are determined by the quantity of motor units active at a given moment, frequency of discharges in each of them, and degree of synchronization thereof. With isometric contraction, the EMG area is proportional to the force of contraction, but when determined, this function is impaired, since there is greater synchronization of motor units. For moderate and average loads, the mean amplitude is a measure of force and mean frequency a measure of load. Thus, the "integral" EMG with measured loads permits investigation of the fatigue process, and in the case of spontaneous activity, it permits evaluation of mean expenditure of energy [force], which has a direct bearing on the study of energy metabolism.

The first research in flight had as its goal to compare the level of spontaneous muscular activity under normal, increased, and decreased gravity. In view of the fact that the animal's head participates actively in all motor reactions (exploratory, alimentary, protective), the electrodes were implanted in the region of the cervical splenius. To obtain control tracings, a 2-2.5-kg weight was suspended from the dog's head. This was associated with static muscular tension, which was well recorded by the above method.

e) <u>Electroencephalography</u>. The differences in electric activity of the brain in calm waking, sleeping states, and intensive mental work are well known. In the USSR, the EEG was recorded during the flights of Vostok 3,6 and Voskhod 1, while the cosmonauts were working actively, during communication with ground bases, and while performing various work operations. In the USA, EEGs were recorded during the first 55 hours in flight on F. Borman, on Gemini 1, while awake and asleep.

Several methodological problems had to be solved to record the EEG under space flight conditions: secure contact between the electrodes and scalp for several days; choice of the most effective, from the standpoint of medical monitoring, and most interference-free EEG leads; placement of electrodes in the space inside the helmet in such a manner as not to elicit discomfort or difficulty in working [94, 98, 124]. In the course of solving these problems, different variants of EEG examinations were tested. EEG recordings were made from different points of the skull, monopolarly and bipolarly, with investigation of reactions to opening and shutting the eyes and rhythm assimilation. A study was also made of the interference-free quality of tracings while blinking, clenching the jaws, turning the head, moving hands and body. Soviet investigators chose the "forehead -- occiput" lead. To assure reliable prolonged contact between the electrodes and the skin, contact pastes and depilatory agents were used. Electrodes similar to those used for EKGs, along with a porolon washer-liner, was mounted on the inner surface of the helmet. The wiring was sewn under the lining and led out to a common connector. This system of derivation of biopotentials was tested in experiments lasting many days and yielded good results.

Special preamplifiers were developed to permit recording the EEG by means of the already existing EKG channels in the on-board equipment. The use of preamplifiers worn by the cosmonaut, aside from purely technical advantages, is also significant with respect to improving the interference-free quality of the EEG channel. EEGs recorded during flight reflect blinking and motor activity of the cosmonaut. When analyzing the tracings, it is important to select meticulously the segments of the curve free of interference.

American investigators used two pairs of electrodes with recording of two EEG leads on a pen recorder, with a range of 0.5-30 hertz. The electrodes consisted of silver chloride disks in small plastic caps. The caps were filled with electrode paste and attached to the scalp using glue.

The scalp was first treated to remove the superficial layers of epidermis. At the site of the electrodes, there were depressions in the helmet lining to assure comfort during lengthy recordings. In this experiment, attention was concentrated on evaluation of the sleeping state. Two consecutive 20-second segments of the tracing were analyzed every 2 minutes. While the cosmonaut was awake, 30-second segments were analyzed every 10 minutes. Evaluation of the tracings was made on the basis of computer analysis (see below).

f) Electric resistance of the skin. There are two methods of recording galvanic skin reactions: according to Tarkhanov (recording electric potentials of the skin) and according to Ferre (recording electric resistance of the skin). Both methods yield identical results. Galvanic skin reactions are considered to be an indication of alertness and consciousness of the pilot. Various emotions -- excitement, fear, terror -- are distinctly recorded by this method, so that it is recommended in many programs for telemetry in space research.

Two types of instruments were developed to record galvanic skin reflexes in flight: one to measure the absolute resistance of the skin and slow changes therein, and the other to record only the fast oscillations of resistances. On Vostok 8 and Vostok 4, the former type of instrument was installed, and on Vostok 5 and Vostok 6 the latter type. The electrode problem turned out to be quite complicated. It was necessary to provide for lengthy recording of electric resistance of the skin, whereas, as we know, even in brief tests, errors are observed, due to increase in interelectrode resistance as a result of impaired contact and polarization phenomena. Furthermore, it was necessary to preclude discomfort in view of the prolonged presence of electrodes on the skin. Under space flight conditions, it was necessary to implement recording lasting several days. The use of electrodes of the same type as for electrocardiography, proper treatment of the skin and choice of appropriate paste solved this problem. The electrodes were placed on the plantar and calcaneal surfaces of the cosmonaut's foot and immobilized with an elastic bandage.

The nonspecificity of galvanic skin reactions makes it imperative to constantly compare them to other physiological indices, to the radio conversation record, and to the television image. At the present time, it is difficult to assess the value of this method for medical monitoring, and more knowhow must be gained in recording spontaneous and induced reactions under different stress situations.

g) Methods of studying efficiency. Under space flight conditions, the diversity of the cosmonaut's activities furnishes extensive material to evaluate his efficiency [fitness]. Radio contact, entries in the spacecraft log, special observations, procedures pertaining to maneuvering the spacecraft -- docking, extravehicular activity, re-entry procedures -- all this professional activity characterizes the cosmonaut's efficiency.

Investigation of tension and fatigue processes in the cosmonaut is of practical value only if it is possible to obtain immediate [operational]

results. This would permit taking steps such as reduction of load, reassignment of duties, addition of stimulators, etc. according to predictable impairment of efficiency.

In evaluating the work done by cosmonauts, the results of psychophysiological measurements, including verbal responses during flight, accuracy of performing different operations and time spent on them, data obtained from television monitoring of work movements [27] are taken into consideration. The simplest behavioral problems can be studied on animals. Thus, observation by means of television of dogs on the second and third Soviet satellite-spacecraft resulted in several important conclusions as to the capacity of the animal organism to perform purposeful acts in weightlessness.

Special investigations were conducted on the American Biosatellite 3. A monkey was trained to solve two problems: to perceive a symbol presented to it and find a similar one, and a videomotor problem for coordination of arms and eyes. For the first problem, a panel was mounted, consisting of five windows (one in the middle and two on the periphery), in each of which one of two symbols could be chosen by means of switches: square, triangle, circle, X. The monkey had to correctly pick the symbols in the peripheral windows until the symbol in the middle one, where it is shown for 18 seconds, disappears.

The videomotor function problem is based on using two concentric rings around a circular screen. The outer circle has a cone-shaped opening, 12 mm in diameter, and the inner one has a microswitch which, when the rings are rotating in opposite directions, coincides with the opening for 45 seconds. The monkey had to observe the reciprocal position of the ring and opening and depress the button at the moment they coincide. In both problems, the monkey was given a food tablet for every other correct solution. A computer was used to control the signals on the panels and to record the test results [87].

5. Biological Analysis of Body Fluids

Deep enough investigation of the mechanisms of reorganization of neurohumoral regulation under unique conditions would be impossible without biological analysis of the fluids of the organism. It is extremely important to perform urinalysis and blood tests to diagnose a number of illnesses. Under space flight conditions, there are some difficulties to such problems. Without dwelling on the blood, urine, and saliva tests presently performed, specimens being collected before and after flights, we shall discuss here the system of automatic urinalysis used during the flight of Biosatellite 3 [64].

Urine was collected from the monkey using a silicone rubber catheter implanted in the bladder. The automatic urinalysis instrument is 30×17×13 cm in size, it weighs 6.8 kg, and uses 6.5 watts of power. The instrument contains all the necessary reagents to perform 450 analyses in 30 days.

Calcium, creatinine, and creatine levels in urine were estimated. Analysis was made in a clear cylindrical container, and light is flashed through its walls. Fluorescence is studied in the calcium analysis, and creatinine color absorption in the creatinine test. The container is filled and emptied with a plunger. There is also a pump that is used to wash out the chamber after completing the analysis and delivery of calibration solutions. The maximum volume of urine for analysis constitutes 2 cubic cm. The photo-electric cell signal, proportional to the concentration of the element being analyzed, is inputted in the form of binary code to the data processing sub-system, then to the telemetry system of the spacecraft. Figure 6 illustrates the functional diagram of an automatic urine analyzer. The logic control circuit is the command center of the instrument; its principal element is a timer that receives daily and hourly signals from the spacecraft instruments and generates successive commands for two analyzers at 0300, 0900, 1500, and 2100 hours. Each successive command is designed to control the corresponding valves, pumpts, and devices throughout the measurement cycle, until the data are outputted in the telemetry device.

At the present time, it is planned to install automatic urine, blood, and saliva analyzers on orbital stations. Such instruments are in the designing or development stage. In addition, studies are in progress of the informativeness of different biochemical indices, in order to determine which methods of gathering and analyzing information are the most effective under space flight conditions [89].

III. ANALYSIS AND EVALUATION OF DATA

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1. Automation of Medical Measurements

The broadening of research problems and need to increase the reliability of medical monitoring are related to the increase in quantity of data subject to transmission from a spacecraft to earth. At the same time, diagnostic and prognostic problems arise, and to solve them it is necessary to use increasingly complex methods of data analysis. In this connection, automation of medical and physiological measurements and use of electronic computers are acquiring much significance in space medicine. At the present time this direction is being developed in two aspects: 1) development of on-board systems of automatic data analysis and 2) use of computer technology to process telemetry data on earth.

When considering the possibility of transmitting the maximum quantity of data through channels with limited capacity we should, first of all, refer to the theses of information theory, and in particular to those of its branches that deal with methods of optimum coding. Thus, with reference to the EKG, we are dealing with a periodically strictly repetitive process (with the exception of extrasystoles). If we extract only the necessary (useful) information from the report,   tens and hundreds time less capacity will be needed in the telemetry channels than for transmission of the original report [11]. An algorithm of extreme formalization has been proposed. It consists of determination of the positive and negative extremes and development of a code characterizing the EKG type. The authors propose using the method of extreme formalization, for EKG transmission via telemetry channels with small capacity, with computation of the chief intervals on the tracing and transmission of a series of numbers, of which the first indicates the type of curve, and the following ones the values of the intervals. For complete transmission of the EKG six numbers are required, instead of the 100-200 with direct quantization.

Many authors [36] have tried to describe the EKG using a minimum number of measurements. For example, it had been suggested that the EKG

be approximated to the Fourier sine series [7]. In this case, 20 readings would reproduce the EKG form with an accuracy of 1-2%.

The principles have been developed for coding electromyograms and EEGs for transmission on the same telemetry channel of data from four biopotential leads. The coding principle consists of determining the frequency and amplitude characteristics of the process and shaping signals that reflect these characteristics [46].

An automatic logic device evaluates the set of parameters according to assigned criteria. These devices operate on a "rigid" program which is determined by the design of the instrument. Different times of automatic logic devices are described in the literature [35].

One of the first designs of an on-board automatic logic device was the system of McLenan (1959)[105]. This system is designed to output to the telemetry channel information about the physiological condition of the cosmonaut. It operates on the principle of a scanning device to review all of the data coming from the cosmonaut, followed by binary selection for each channel and formation of an arbitrary signal (code) using simple logic systems of the "and" and "no" type. The system is designed to process data about the efficiency and physiological condition of the cosmonaut.

Electronic digital computers offer utterly new opportunities in the area of formulating and solving problems of medical monitoring, diagnostics, and prognostics in space. The present level of medicophysiological knowledge already allows us to design on-board diagnostic devices, whereas the level of technology makes them reliable enough and provides for appropriate size and weight indices.

At present much knowhow has been gained in using electronic computers to analyze biomedical data in clinical physiology. The first steps have been made with respect to using computer technology to solve specific problems of space medicine. We shall discuss in the following three examples of using mathematical methods to analyze data obtained during space flights. These examples pertain to neurophysiological and cardiological investigations.

A. Computer analysis of EEGs. To analyze the sleeping state during space flights, computer analysis was made of EEGs made on astronaut F. Borman on Gemini 7. The telemetry data were recorded on magnetic tape, then analyzed in the space medicine laboratory of the University of California.

The analysis methods were developed on the basis of searching for correlation between the EEG and attention and psychological tension [62, 65, 67, 68]. Auto- and cross-correlation, as well as auto- and cross-spectral methods were used. The coherent function was computed as the statistical measure of correlation between adjacent biopotential regions at each frequency:

$$con = \{[Avet(PP'+QQ')]^2 + [Avet(PQ'+QP']^2\} /SS',$$

where con is the coherence function, Avet is time averaged value, P and Q are input values of digital filters according to phase squared with an axis at a frequency of f(-), P', Q', and S' are the results of filtration of the second channel. The analysis data were entered on special graphs, circuit cards on which the coherence values were plotted on the x axis and the frequencies on the y axis. Total time required to analyze each card was 8 minutes, and two successive 12-second periods were processed. Using the computer, the highest and lowest points were marked on the card, and lines traced of equal density spectra.

In order to obtain initial data on normal values and investigate individual EEG distinctions of different states, candidates and cosmonauts were examined [1117]. Tracings of good quality were obtained on 200 people who were tested to solve recognition and training problems using a programming device. A data file was made up for 50 out of the 200 subjects, with reference both to rest periods and selected sleep periods. As a result a spectrum graph was obtained, from 0 to 25 hertz, for each part of the integument (Figure 7).

Cards with the results of processing data obtained during space flights were made up for every two consecutive areas, 20 seconds each, for 2 minutes (during sleep), and for 30 seconds each every 10 minutes (waking). These data were compared to the initial EEGs of F. Borman, including the data in the "norm file" and those obtained in simulated flight. Using this method, it was shown that one minute before lift-off, the area of intensified theta rhythm merges with increasing oscillations in the alpha and beta rhythm zones. This is related to great concentration and orientation reaction. Immediately prior to lift-off and immediately after it, the density of EEG voltage increased by about 10 times in many areas, as a reaction to marked nervous and physiological excitement. Then these increased densities slowly diminished in the frequency band above 10 hertz within the first 30 minutes of flight. The existence of different variants of experimental research on EEG coherence in different situations explained the high levels of coherence in the 3-9-hertz range at the end of the first orbit. These findings are inherent to a relaxed state occurring after strong psychic emotions.

B. Mathematical analysis of heart rhythm. In recent years, mathematical analysis was made of dynamic series of RR intervals on the EKG by Soviet researchers in experimental physiology, clinical practice, physiology of athletics, and space medicine [7, 26]. The sequence of intervals was viewed as a random stationary process with the property of ergodicism [46]. In evaluating the data obtained by different authors in the area of sinus arrhythmias, we can conclude that there are mechanisms that directly influence the sinus node (autonomic regulation) as well as mechanisms that control cardiac rhythm via the cortical-subcortical levels (central regulation).

The sinus node is a sensitive indicator of changes at all levels of control. The respiratory fluctuations of rhythm are related essentially to

disturbances in the self-regulating system, whereas nonrespiratory fluctuations are related to the function of central, mainly neuroendocrine, systems [51]. On the basis of these considerations, it may be believed that a dynamic series of EKG intervals should contain information about the state of each of the regulation circuits, as well as nature of interaction between them [52].

The feasibility of judging the nature of neurohumoral regulation of circulation according to cardiac rhythm and of drawing some conclusions as to the state of the entire organism is particularly important to space medicine, where the volume of physiological data transmitted from spacecraft to earth is limited.

Segments were picked for analysis from the telemetry tracings of EKGs or SKGs [seismocardiograms] including 100-120 cardiac cycles. This sample size was determined to be sufficiently reliable statistically in view of the fact that within the framework of a single telemetric communication session such a volume of data could always be distinguished from a background of noise related to both technical reasons and motor activity of the cosmonaut.

Four methods were used to analyze dynamic series of RR intervals: histography, autocorrelation, spectral, and cardiointervalography.

Histography, or variation pulsimetry, demonstrates the law of distribution of the index in question. The type of distribution and type of variation curve are related to the state of the autonomic nervous system.

The autocorrelation function was calculated to demonstrate the internal structure of the process. The more homogeneous the dynamic series of RR intervals under study, the slower autocorrelation functions will reach zero, and the more stationary the process. A nonstationary process shows a sharp drop of correlation coefficient to zero, even after the first shift. Decentralization of control leads to intensification of respiratory arrhythmia, and the autocorrelation function, which rapidly reaches zero, then indicates the presence of respiratory periodicity. In a state of tension (work, emotion) a very slow drop of autocorrelation function is observed. The process becomes more stationary and respiratory periodicity levels off.

The presence of periodic fluctuations in the process under study can be demonstrated on the cardiointervalogram or autocorrelation function, however, spectral analysis is the most effective for quantitative evaluation of different periodic components [52].

Investigation of slow waves of cardiac rhythm is of great interest; apparently, they have a direct relation to the activity of neuroendocrine mechanisms of regulation. Cardiointervalography is the simplest method of demonstrating such rhythms. Compression cardiointervalography -- summation of time for 10, 30, and 60 beats, was used to smooth the respiratory waves. This demonstrates waves with periods of 30 to 150 seconds [52].

The diagnostic and prognostic value of such analysis was confirmed in a study of cardiac rhythm of operators performing monotonous work. It was shown that appearance of marked slow waves (30-100 seconds) was one of the early signs of mental fatigue and it preceded an increase in number of errors made in the operator activity [7]. Onset and intensification of slow waves could be attributed to "disinhibition" of subcortical structures as a result of development of extinction inhibition in the cerebral cortex.

The above methods of mathematic analysis of cardiac rhythm were used to process data obtained during the flights of Soviet spacecraft and satellites. Variation pulsimetry was first used to assess the condition of cosmonauts V.F. Bykovskiy and V.V. Tereshkova [49].

The first experience in using autocorrelation analysis was referable to M.D. Venttsel and A.D. Voskresenskiy, and N.A. Chekhonadskiy [22], to analyze the data on the Voskhod flight. It was established that along with respiratory variations of cardiac rhythm there are also slower fluctuations (with a period of 70-80 seconds). During flight there was a tendency toward longer periods of slow waves and longer time of extinction of autocorrelation function to zero. These changes are indicative of intensification of centralized control of cardiac rhythm. As a result of spectral analysis of slow waves in cosmonauts [49], it was shown that the activity of central regulatory mechanisms was greatest during the first orbit. As a result of autocorrelation and spectral analysis of cardiac rhythm, it was established that there are individual types of autonomic regulation: normotonic in V.M. Komorov, vagotonic in K.P. Feoktistov, and sympathicotonic in B.B. Yegorov.

During the long flight on Soyuz 9, variation pulsimetry demonstrated changes related to emotional stress (1st, 15th, and 19th days of the flight) and readjustment of regulatory systems (12th day), when only the amplitude of distribution mode increased with unchanged in other statistical indices. The emotional changes on the 1st and 19th day are understandable, marking the start and end of the flight, and the 15th day was apparently one of emotional tension due to the fact that on this day V.N. Nikolayev and V.V. Sevastyanov surpassed the prior record set by the crew of Gemini 7 as to length of time spent in space. Of some interest are the variation pulso-grams obtained while the cosmonauts slept. From them, it can be concluded that along with deep sleep when there is marked prevalence of vagal tonus, there are times of "intense" sleep when the variation pulsogram presented sympathotonic features. Figure 8 illustrates samples of variation pulsograms in different functional states.

C. Spectral analysis of the seismocardiogram. Seismocardiography is one of the derivatives of dorsoventral ballistocardiography and bears information about oscillatory phenomena associated with cardiac contraction and shift of blood masses to the major vessels. The cardiovascular system constitutes the sum of oscillators generating oscillations of different frequencies and amplitudes. As we know, the ballistocardiogram reflects pulse fluctuations of the body's common center of gravity; such techniques

as kinetocardiography and vibrocardiography permit recording local oscillations. Seismocardiography differs in that it shows, integratively, the fluctuations of the entire chest wall without picking up, like ballistocardiography, body movements as a single system. Thus, it can be assumed that in seismocardiography the oscillatory processes are mostly related to activity of the heart proper.

SKG spectra were studied using a method developed under the guidance of Professor V.A. Zverev as applied to BKG analysis. The logarithms of the spectra are studied by means of an optic analyzer. From 2-3 to 8-10 cardiac SKG complexes are analyzed, with a resolution of up to 0.1 hertz. SKG spectra can be interpreted by analogy to BKG spectra, since they reflect the same phenomena, the only difference being that there are no oscillations in the SKG spectrum that are related to the actual frequency of the "earth -- ground" system (5-6 hertz). This permits interpretation of the correlations between the first and second harmonics of the spectrum and increase in its width in relation to impairment of normal correlations between the right and left heart. It was shown that in progressive mitral stenosis, which is characterized by gradual increase of pulmonary hypertension, increased load on the right ventricle, and relative underload on the left ventricle, predominance of second harmonic over first is observed. The width of the spectrum increased from 14±0.7 hertz, which is normal, to 18±0.4 hertz (P 0.001). These changes correspond to greater changes in the ballistocardiogram [31].

Figure 9 illustrates the seismocardiogram spectra of cosmonaut V.A. Dobrovol'skiy, commander of the Salute 1 orbital station, on different days of flight. As compared to the spectra referable to the prelaunching period and first day of flight, there is subsequent gradual broadening of the spectrum from 25-30 to 45-50 hertz, and some drop in amplitude of the first harmonic. In view of the fact that the data of spectral seismocardiography constitute the only information about changes in the state of the heart and pulmonary circulation during flight, such data should be considered of prognostic value.

2. Questions of Medical Monitoring and Diagnostics

Analysis and evaluation of data obtained during space flights are directed toward solving problems of medical monitoring, diagnostics, and prognostics. At the present time, medical monitoring is based on current [operational] evaluation of telemetry, television, and radio communication data, and attention is focused primarily on the cosmonauts' general well-being and condition, their efficiency. Aside from the vestibulovegetative disorders, specific manifestations of the effect on the organism of weightlessness have not yet been observed. Consequently, the criteria for evaluation of the physical condition of cosmonauts and decision making are based on the usual clinical conceptions. On the basis of practical problems, the following classification of states of the organism can be introduced: normal, state of tension [or stress], threatening state, and critical state [27]. Such classification is definitely arbitrary, but it permits development

of a system of identifying states according to rather concrete signs that can be obtained during flight.

When developing diagnostic algorithms applicable to on-board conditions, a number of factors must be taken into consideration: nature of initial information, means of expressing it for input to a machine, methods of analyzing and evaluating data, and others. The choice of parameters to be monitored is of utmost importance. As we have already stated, the problem generally consists of minimizing input data without diminishing the effectiveness of diagnostics. The concrete choice of parameters depends on the duration and objectives of the flight, type of spacecraft, composition of the crew. The theoretical aspects of choice of a set of parameters for medical monitoring in space flights is based on the criteria of need and adequacy of parameters (including analytic methods) to be able to diagnose changes in the main physiological functions and efficiency of cosmonauts under the influence of flight factors, the possibility of prognosticating reactions and differentiating between physiological and pathological states, including identification of specific reactions [42]. The following can be mentioned as concrete monitoring problems in flight: investigation of distinctions of neuroendocrine regulation, degree of tension and correlation bttween indices, by means of determination of deviations from proper values or calculation of correlations. In order to make a quantitative evaluation of the effects of different factors on the physiological indices under study, it is suggested that covariation analysis be used.

It is imperative to develop basically new methodological procedures, in particular, "no-contact" systems of gathering data, methods for examination of the internal medium of the organism, and appropriate examination programs to back up long space flights [48]. There is a need to develop express methods of gathering the necessary data, while algorithms are needed for rapid receipt of recommendations using the on-board computer.

Development of on-board systems of automatic data processing will open the way, first of all, to back up current medical monitoring, by means of transmission of summarized computer data to earth via narrow-band telemetry channels as well as independent use of data on board the spacecraft. We concur completely with authors who indicated that it is impossible to diagnose an illness by means of an on-board computer [28]. It can only be a question of identifying dangerous conditions and reporting them promptly. As for the processing of medical data on board a spacecraft, programs for this purpose could vary, depending on the capability of on-board computer devices, availability of additional equipment, and volume of data [33]. In choosing automation systems, the algorithm of data processing is of utmost importance. The following conditions must be taken into consideration with reference to an on-board computer: 1) data are inputted directly from the cosmonaut; 2) the computer capabilities are limited as to speed of operation and, especially, memory; 3) in solving problems pertaining to current monitoring, it is necessary to provide, at the same time, for transmission of data obtained to earth through a narrow-band communication channel. Here, the first problem that arises is that of inputting data to

the computer. Regardless of whether the data are inputted as pulses or quantized values of the parameter in question, they are converted into a series of numbers stored in the immediate-access memory of the computer. These data can subsequently be analyzed in three ways [11]: 1) reproduction of known clinicophysiological methods of analysis, for example, isolation of specific EKG intervals and waves; 2) bionic; 3) mathematical-statistical.

The first of these directions refers to methods of amplitude and time analysis, since the most common method today is determination of time intervals and wave amplitudes of different oscillograms, calculation of indices and indicators. The medical algorithm of such analysis is not complicated, however, from the standpoint of the computer programmist, this is the most complex form of analysis, since exact identification of different waves and intervals on the tracing is required. Actual demonstration of set amplitude and time indices often becomes a most complex logic problem.

The bionic direction is related to the problem of pattern recognition. The machine simulates the activity of an experienced specialist who determines the nature of deviations or makes a diagnosis according to the appearance of the curve alone, without making any calculations. Like a physician, the computer compares the data inputted to the standards stored in its memory. The standard closest to the curve under study is retrieved and its number reported to the doctor.

The mathematical statistical method of analysis consists of calculating a number of strictly mathematical indices and functions. This is an unfamiliar form of analysis for a physician, but is the most adequate for the computer. Experience in histographic, autocorrelation, and spectral analysis of a dynamic series of cardiac cycles revealed that mathematical methods of analysis demonstrate distinctions of physiological functions that would have required extensive examinations to be identified by the usual techniques. Thus, on the basis of mathematical analysis, it was possible to prepare the algorithm for monitoring the cosmonaut's condition with only one parameter available: rhythm of cardiac contractions [51, 7].

These methods of analyzing medical data can also extend to physiological processes recorded in both micro- and macro-intervals of time. It is possible to obtain new and effective diagnostic criteria in this manner.

3. Questions of Predicting Man's Condition in Space Flight

Problems pertaining to prediction of the physical condition of cosmonauts are acquiring more and more urgency in view of the longer duration of flights. However, it turned out that the solutions were very complex, in view of our inadequate conceptions of the mechanisms of formation of pathological shifts in the organism under the specific conditions of weightlessness. Several investigators have even voiced the view that it is impossible to predict human endurance of prolonged space flights on the basis of existing knowhow and knowledge [113]. Indeed, we cannot use here the traditional approach to prognostication of clinical practice and

physiology, when the condition or illness whose course and outcome must be predicted have been observed many times at different stages of development thereof. Unlike the conditions on earth, the adverse states and changes that must be predicted have not yet been observed in space (with, perhaps, the exception of seasickness). Thus, we do not yet have any facts to design a system of prognosticating expected pathological states.

The demands of practice dictate, in some cases, an empirical approach to prognostication, for example, the results of the Gemini and Apollo flights were used to predict the satisfactory tolerance of cosmonauts to the moon [74]. There are only isolated attempts, in physiology of stress factors, at predicting development of some reactions and conditions, on the basis of consideration of initial data or analysis of the dynamics of the ongoing process in thermal collapse [20], decompression [114], operator activity [55]. As applied to long space flights, the forecasts of Ditlein [81] merit attention; in 1964, he described a system [scheme] of possible development of symptoms as related to different duration of flights.

At the present time, we can distinguish three categories of methods of forecasting man's condition in prolonged space flights.

1. Methods based on use of the knowhow and intuition of highly qualified specialists emerging as experts. These methods have been developed in the area of scientific technological forecasting and were named heuristic, since they are used under conditions of high degree of uncertainty [47]. During the flight of the Salute orbital station, a variant of heuristic forecasting was used: the method of expert evaluations. A good coincidence was obtained between the predicted and current parameters of the medical monitoring system. This indicates that it is purposeful to continue development of this direction of work.

2. Methods based on the use of functional characteristics of the object on which the prognosis is made and of correlations between them. Differential equations or discrete algorithms are used to approximate the data as function of time. Mathematical methods provide for short-term prognosis of dynamic processes and development thereof as applied to problems of space medicine, and they are of great scientific and practical interest.

3. Methods based on knowledge of concrete laws of function of the object of prognosis. This category of methods is the most attractive to space medicine, since it opens the way for broad practical use of the knowledge accumulated to the present time about man's reactions to stress factors.

We shall discuss two variants of forecasting systems being developed in the USSR and USA, on the basis of the last of the above categories.

A. Investigative (research) prognosis [12]. Since we cannot, within the framework of existing scientific knowledge about the effects of space flight factors on the living organism, build a system of prognostication

of expected pathological states, the concept of standard prognosis cannot apply to solving this problem. However, there is another approach to prognosis, called investigative or research [exploratory?]. This is how one of the founders of modern forecasting, Erikh Yanch (1970), defines the difference between these approaches: "Investigative forecasting starts with the base of knowledge available at the present time and is directed toward the future, whereas standard [norm] forecasting first assesses future goals, requirements, desires, and proceeds in the opposite direction, toward the present" [60].

The working hypothesis of investigative prognosis proceeds from the well-known thesis that tension of regulatory systems, including the sympathoadrenal system, and cortical mechanisms of regulation are common to all adaptive reactions of the organism in response to stress factors. This leads, as we know, to mobilization of protective systems that assure the necessary end effect [5] by beginning to function in a specific sequence and, in some cases, ahead of development of the pathological process. Overstrain of regulatory systems could lead to a breakdown and then appearance of pathological syndromes or illnesses. Consequently, the stress [tension] state could be viewed as the state typical of the first stages of development of any pathology, and it could be adopted as the base in investigative prognosis. We refer to the presence of both positive and negative vectors of this state as projected into the future. Introducing the arbitrary term, "vector of state," we define it as the characteristics of severity and tendencies of development of a current state of the organism. Thus, the focal element of research was to find criteria that would permit detection of a tendency to change in the stress state, in the direction of normalization of overstress, i.e., to determine the vector of state. It should be noted once more that stress state does not imply emotional or physical stress alone, but also the changes in regulatory mechanisms that are associated with any readjustment of a functional system to a new level of reacting. Such changes can be either specific or nonspecific. The latter are mostly referable to the sympathoadrenal complex.

The search for prognostic criteria, i.e., fine indices of current condition and tendencies toward change in physiological functions, proceeded on the basis of a hypothesis that postulates that all states undergo the following four stages [50]: 1) stage of temporary nonconformity of functions; 2) stage of impaired flow of information; 3) stage of impaired energy metabolism; 4) stage of structural disturbances. Consequently, to solve prognostic problems, it is purposeful to investigate the level of temporary organization since changes at this level precede informational, energetic, and structural disturbances.

Thus, the proposed method of prognosis is based on two principles: determination of tendencies toward change in stress state in the direction of normalization or overstress; 2) search for prognostic criteria on the level of temporary organization of functions.

Figure 10 illustrates the difference between standard and investigative prognosis. On the horizontal line is shown the scale of states and state

vectors corresponding to the prognostic principles adopted in clinical practice or proposed for space medicine. On the vertical line are shown the levels of organization of a living system: time -- information -- energy -- structure. As we see from the arrows going diagonally, the prognostic criteria should be in effect primarily in the prognosis areas corresponding, on the one hand, to the borderline state between normal and tension [stress], and overstress, on the other hand -- levels of informational and energetic changes.

In the course of work, methodological procedures were used which permitted obtaining information about the state of neurohumoral regulation of functions and the circulatory system. Only methods that had either been used already or could be used in the future for direct, on-board readings on a spacecraft were selected. The choice of prognostic criteria was based on indices of temporary [or time-related] organization of functions. Two types of fluctuating processes in the organism were investigated: circadian (with a period close to 24 hours) and cardiac-respiratory rhythms (periods of 0.5 to 10 seconds).

The circadian periodicity of functions was studied according to pulse rate, body temperature, and sodium concentration in mixed saliva [13]. The last parameter is related to the condition of the sympathoadrenal system and may be viewed as an index of adjustment of control systems of the organism to a set rhythm of work and rest, and as an indicator of degree of tension of mechanisms of function regulation [13]. Cardiorespiratory rhythms were studied by means of mathematical analysis of dynamic series of RR intervals on the EKG with construction of histograms and autocorrelation functions (see above). Changes in the statistical characteristics of cardiac rhythm are an important index of activity of the sympathoadrenal system and state of neurohumoral regulation of the circulatory system [51]. Factors that simulate some of the space flight conditions were used as the experimental factors.

Studies were made of the adaptive reactions of the human organism to experimental hypokinesia, artificial and natural time shifts, anti-orthostasis, and combinations of these factors. As a result of a series of studies, including investigation of the range of normal variation of the indices chosen, development of models of different states, and investigation of adaptive reactions to the above experimental factors, it was established that determination of individual types of adaptation and examination of the functional reserve of the organism are important in predicting probable pathological changes, in addition to determination of the severity and direction of stress reactions.

For current evaluation of normal, tension, and stress [overstress] states, the statistical characteristics of cardiac rhythm (M, Mo, AMo, Δ, X), data on sodium level in mixed saliva, indices of synchronization of functions, and circadian parameters can be used. A tendency toward excessive decline of all these indices (for AMo -- a rise) is prognostically unfavorable, and indicates development of overstress of regulatory systems,

which could ultimately lead to breakdown of regulation, severe asthenization, and appearance of specific syndromes. As an example, Figure 11 illustrates the graph of changes in pulse, body temperature, and saliva sodium content during an experiment with 64 hours of sleep deprivation [8]. As compared to the background, during the experimental period there is a decline of mean 24-hour sodium level in saliva and marked desynchronization of functions. Three days were found to be inadequate for complete recovery of the initial state.

The duration of the recovery period as related to different tested factors is one of the indices of functional reserve of the organism. Significant asthenization eliciting regulatory disturbances is manifested by an inadequate reaction to loads. The amplitude of daily fluctuations of different parameters can also serve as a good indication of functional reserve, since it reflects the organism's response to routine "natural load," the change in environmental conditions. It is purposeful to use the difference between levels of function or parameter at rest and during activity as the index of amplitude of daily fluctuations. An index of daily adaptivity (PSad) has been proposed, defined as the percentile ratio between the 7 and 11-hour difference in value of the parameter to the initial 7-hour value [12].

In order to establish the individual type of adaptation we must know the distinctions of regulatory systems of the organism. Just as I.P. Pavlov described the properties of the chief nervous processes in the cerebral cortex by their force, balance, and lability, it would be purposeful to develop analogous criteria for systems implementing interaction between the organism and environment. Thus, a classification of types of adaptation may be offered according to lability of functional systems, as related to the problem of screening cosmonauts for brief and long flights. The extreme types -- inert [sluggish] and flexible -- are notable, respectively, for faster or slower readjustment of the organism to a new level and rhythm of activity. Various experimental factors can be used as tests for lability of functional systems: orthotest, physical load, administration of pharmacological agents. The rate of transition of the organism to a new level of function or rate of recovery of the initial level are measured. In the tests with time shifts, the sluggish type of adaptation, in contrast to the flexible, is characterized by slower synchronization of circadian and set rhythms [12]. In the antiorthostasis test, individuals with good flexibility of regulatory systems were characterized by a greater range of changes in cardiodynamic parameters in the course of adjustment to a new functional level. The passive orthotest performed immediately after orthostasis was usually well tolerated by such individuals. When using the method of phase plane to analyze individual adaptation types, tolerance of orthostatic tests could be forecast according to the "area of regulation" (region circumscribed by the phase trajectory of the system of parameters under study) and vector of transition (magnitude and direction of the segment of the phase trajectory in the first minute after switching the subject from antiorthostatic to orthostatic position). A small area of regulation and large transition vector are prognostically unfavorable [12].

Thus, prediction of the condition of the organism exposed to stress factors, from the standpoint of investigative prognosis, permits working out a number of effective criteria to evaluate the direction of the adaptation process, severity of stress state, individual type of regulation, and functional reserves of the organism.

B. Clinicofunctional approach to prognosis. The changes in functional state of the organism under space flight conditions could be viewed as quantitative and qualitative shifts due to a change in functional reserve and defense capabilities. We refer to detection of early and minor changes in different systems and organs in the course of extensive and diversified examinations. The specialists of Beckman Instr. Co. believe that the reserves of the organism can be evaluated by monitoring the liver, endocrine, and hemopoietic systems, since all metabolic and stressor changes are related to them. The defense capabilities of the organism and its susceptibility to stress can be assessed by estimating the globulin level, the state of the leukocyte system, determination of phagocytes and leukocytes, as well as microbiological studies. The problem is to detect microsymptoms of changes that are not per se symptoms of illness and that appear long before onset of illness [89]. It is assumed that the true picture of the changes can be detected only through intensive periodic examinations involving many readings and comparing them to the initial data.

On the basis of this conception, Beckman Instr. Co. together with Lockheed Corp., under the guidance of NASA, are developing a system of biochemical and hematological analyses in space, including collection and storage of biofluids and adaptation of a number of clinical techniques to space flight conditions. In gathering initial data, it is planned to devote special attention to investigation of circadian rhythm of functions and fluctuating phenomena in different systems of the organism. A number of tests is being developed to demonstrate primary responses to stress. Importance is attributed to metabolic studies, and in particular to changes in blood sugar and calcium.

In developing a system of prognostic readings in space, specialists consider it imperative to collect blood at specific intervals, but not too often. Emphasis is made on examination of natural fluids: sweat, saliva, and tears. Special attention was given to the study of salivary gland secretion. Special techniques have been developed to collect and automatically analyze salivary secretion with telemetry of the measurement results. Saliva will be examined in a daily cycle; potassium, sodium, calcium, albumin will be estimated in saliva, globulins, proteins, glucose, and lipid components, etc. -- in blood. The pH, proteins, and glomerular filtrate will be examined in urine. A biochemical automatic device has been developed, with manual input of material, and automatic analysis with output of the results in a special code to the on-board digital computer.

Extensive and diversified studies are being conducted on earth to obtain data on the range of normal variations and prognostic value of gathered data [115]. It is planned to obtain 400-500 parameters from each

individual, including instrument, biochemical, and hematological measurements, examination of respiration, the digestive, nervous, and cardiovascular systems, and anthropometry. Some newly developed techniques will also be used, such as examination of salivary secretion. Individual variability of the parameters will be investigated by taking readings several times a day. It is planned to conduct such extensive examinations twice a year.

Thus, the system of prognostication being developed in the USA is directed toward demonstration of negligible, subclinical, early changes in systems and organs by means of diversified [multipurpose] automated examination. The area of prognosis is referable to borderline states between normal and stress. The search is directed from normal to subclinical shifts characterizing the functional reserve and protective capabilities of the organism. On the diagram pertaining to forecasting principles (see Figure 10), this clinico-functional approach could be viewed as the first stage of clinical prognostication which ends in the area of borderline states. It should be noted that this approach, in essence, is analogous to the concept of mass preventive examinations whose purpose is early detection of premorbid states.

IV. DIRECTIONS AND MEANS OF FURTHER IMPROVEMENT OF THE SYSTEM OF PHYSIOLOGICAL
MEASUREMENTS IN SPACE

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The methods of examination and problems of transmission of biomedical
data being developed at the present time by space medicine are the foundation
for future research with respect to medical back-up of long flights on
orbital stations and interplanetary craft.

Lovelace and Schwichtenberg indicate that the farther man is from
earth, the more difficult it is to assure his safe existence and return
[97]. For this reason, reliable medical monitoring, collection of physiolo-
gical data on the effects of interplanetary factors on man are growing
to be important [93].

One of the chief distinctions of the physiological data measuring
system on interplanetary craft is the participation of a physician as a
crew member. Many works [73, 99] discuss the need for inclusion of a
doctor in interplanetary expeditions. The long duration of an interplanetary
flight and availability of a doctor on the crew, as well as use of on-board
systems of automatic processing and storing of data makes it imperative to
develop new principles in the design of physical measuring and data systems.
First of all, we need to define the chief problems that are to be solved
by physiological readings on an interplanetary craft. We could mention at
least four such problems.

1. Current medical monitoring performed by the on-board physician
periodically, at different phases of flight.

2. Routine general physical examinations, by the dispensary
system, of crew members in order to evaluate their health and gather
scientific information on the effect of factors involved in long inter-
planetary flight on the physiological functions of man.

3. Medical examinations performed for the purpose of in-depth
monitoring of different systems and organs, and to diagnose illness that
could occur during flight.

4. Transmission to earth of the principal results of all the above physiological measurements.

Medical checks on an interplanetary craft should be made periodically, according to a specific program, as well as extemporaneously, when there is a possibility of dangerous deviations in the physical condition of crew members. It is impossible to anticipate all such situations in advance. We can mention some of them: repair work involving extravehicular activity, significant increase in radioactivity, malfunctions in air conditioning and heat regulating systems, slowing down the craft for maneuvers and landing, etc. In such cases the necessary sensors and electrodes are applied by the doctor (or the cosmonaut himself), and the proper on-board equipment is turned on (here the intracabin telemetry system is used). The data should be inputted in a summarized form (and, if the doctor so wishes, in their primary form) to a specially equipped medical panel. At the same time, these data should be inputted in a memory device then in abbreviated (concise) form transmitted to earth in the course of a scheduled communication session.

There are considerable works [2, 71, 102, 107] dealing with development of systems of in-cabin telemetry. The following are the chief specifications for such systems [7]:

1. The equipment carried by the cosmonaut should be of minimum weight and size with maximum continuous operation time without changing the power pack.

2. A good quality of recording of the monitored physiological parameters should be provided while the cosmonaut is active or when he is in any of the compartments of the spacecraft.

3. The system of electrodes and sensors should not hamper the cosmonaut in his activity and should not cause discomfort when worn for any length of time.

At the present time, several multichannel biotelemetry systems have been developed as applied to in-cabin retranslation of data, including an eight-channel system using amplitude-pulse modulation [178], a number of systems with frequency modulation of audio subcarriers [2, 4], a module system with separate carrier frequencies for each channel [7], a miniature biotelemetry transmitter on a tunnel diode [116], systems with power supplied from an artificially created electromagnetic field [102], with biological power supply [96, 103], and others.

Routine, dispensary-type, medical examinations of the crew should be comprehensive in order to assure prompt detection of even minor health deviations and to obtain complete enough scientific information. A definite set of methodological procedures, standardized and tested in advance, with a wide enough range and concrete program, will permit using reliable algorithms for primary automatic processing of the data on board the spacecraft. A special reference aid will also be needed for evaluation of the results of

the examinations. If we assume that such examinations can be made even once a month, storage of the records accumulated during the entire flight becomes a complicated problem. For this reason, this problem should first be investigated jointly by physicians and engineers, in order to determine the extent of preliminary data processing both for storage on board and for transmission to earth.

Special medical examinations may be referable to those planned in advance in the event of appearance of specific changes in different organs and systems, or planned physiological readings for research purposes; or to the readings required to determine the condition of crew members who developed a set of symptoms not yet known on earth.

The lack of continuous communication between an interplanetary spacecraft and earth, the small volume of medical information transmitted, the impossibility of rendering assistance from earth, with the exception of consultation -- all this makes it necessary to consider in detail the possibility of morbidity among cosmonauts during long flights, methods of diagnosis and treatment under these specific conditions [61, 53]. It must be borne in mind that while a cosmonaut may be considered absolutely healthy at the start of a flight, and his reactivity does not differ in any way from that observed on earth, as time passes his reactivity may change under the influence of flight conditions. Such factors as prolonged isolation and hypodynamia diminish the defense properties of the organism. The factors of interplanetary space may also have an adverse effect on the cosmonaut's organism. As was shown by P.V. Vasil'yev [21], weightlessness and hypodynamia lead to decrease in orthostatic and vestibular stability, increased sensitivity to infection, decreased tolerance of accelerations and physical loads, altered reactivity of the organism to pharmacological agents.

Illness during an interplanetary flight can be classified in one of the following groups: 1) illness due to living conditions (hygienic environment, diet, routine, psychological factors); 2) illness due to the effects of interplanetary space factors (cosmic radiation, electromagnetic fields, weightlessness); 3) pathology related to endogenous factors (autoinfection, impaired nervous and endocrine regulation). The concurrent effect of several factors can apparently elicit complex, serious forms of pathology not known on earth. New nosological entities may also appear, due to the effect of cosmic factors not yet known.

The approach to morbidity among interplanetary crews from the standpoint of probability of onset of different diseases is extremely important to planning of both diagnostic procedures and therapeutic care. Thus, it is certain that the probability of pneumonia or appendicitis during a long flight is greater than of some other illnesses. The possibility of rather frequent disturbances of coronary circulation is not ruled out, since the tension of the flight and living conditions cannot help but affect blood supply and metabolism in the myocardium.

When investigating morbidity during interplanetary flights, one should make broad use of the concept of variable probability of illness. The fact of the matter is that under specific conditions the probability of some diseases increases and of others decreases. Thus, in the case of dietary disturbances there is a greater probability of alimentary dystrophy, avitaminosis, etc.; under the effect of cosmic radiation, there is a greater probability of radiation sickness. If we also consider the diversity of forms of pathology and course, which will depend on concomitant disturbances referable to living conditions or appearance of adverse external factors, it will become clear that complex mathematical analysis is required here, with the use of modern computer technology.

The design of diagnostic systems on a spacecraft has its own specifics related to the following factors: a) the volume of memory and speed of operation of on-board computer devices are limited; b) the most diverse data in the most diverse form are to be inputted to the diagnostic system (oscillograms, directly from man, digital data, complaints and data in code, etc); c) the number of probable diagnoses is quite large; d) sets of symptoms may appear that are not yet known and cannot be anticipated in advance.

The difficulties involved in developing a general purpose diagnostic system on an interplanetary spacecraft could be reduced, to some extent, by preparing special reference microfilm, as well as providing for the solution of special diagnostic problems on the computer on board according to programs that could be developed, if necessary, by mathematicians on the craft, with the participation of the physician. Nor should one forget that consultant aid from earth is available, but this is related to the next problem, that of transmitting data to earth.

It is a known fact that in interplanetary flights there is a limited supply of power on board the spacecraft, and the greater, "astronomical" distances do not permit wide-band and prolonged radio communications. It is assumed that the capacity of telemetry channels and time of transmission will be hundreds of times smaller and that there will be rather limited exchange of information between the spacecraft crew and earth.

At the present time it is difficult to perform the necessary calculations, however, it is quite clear that it will be impossible to transmit either oscillograms or even digital data. Apparently, coded, summarized data will be the chief means of exchanging data with earth. For this reason, one should start, even now, to work on a "new code language" to express all the necessary data and concepts of medicine and biology that may be required in interplanetary flight.

Just as there is an international radical [?], so space medicine should have the necessary means of exchanging information. We should also keep in mind the possibility and need of automatic issuance of the codes by the on-board computer for transmission to earth after each scheduled and unscheduled clinicophysiological examination.

Table 3. Characteristics of physiological measurement-data systems for
different purposes

Short flights (up to 5 days)	Long flights (up to 1 month)	Interplanetary flights
During flight all sensors and electrodes are on the cosmonaut	Only a minimum number of sensors and electrodes for medical monitoring are on the cosmonaut; most are applied by him for brief examination periods	Sensors and electrodes of the medical monitoring system and all other sensors are applied by the on-board physician
Cosmonaut is wired to on-board equipment	In-cabin radio lines are used for medical monitoring	In-cabin radio lines are used for medical monitoring
On-board medical equipment is controlled automatically from earth or on-board programmed device	There is manual control in addition to automatic and programmed	The physician controls the equipment
Physiological data are recorded only during periods of direct communication with land-based centers	The bulk of physiological data is recorded by memory devices during periods without communication with earth, with subsequent automatic transmission of all data to earth	Data are recorded by on-board devices with storage in processed form. Only a small part of summarized data is transmitted to earth
Physiological data are transmitted in the form of oscillograms	Physiological data transmitted only partially in oscillogram form. Most data are transmitted in digital and summarized code form	Physiological data are transmitted to earth only in summarized form

Thus, the system of diagnostic readings on an interplanetary space-craft will differ appreciably from the systems we know of today. The comparative characteristics of three types of physiological measurement systems (for brief space flights, for long space flights, and for interplanetary spacecraft) are given in Table 3.

Problems pertaining to diagnosis of dangerous states should be closely related to solving problems of rendering medical care on board spacecraft. Rapid identification of pathological states has as its goal

speedy rendering of aid, and it should be qualified and effective. In interplanetary flight conditions both diagnostics and care must be automated. Emergency, immediate care, for example delivery of oxygen to one of the compartments, could be given either by depressing the proper button on the physician's panel or automatically, on the basis of generation of the appropriate command by the computer that is performing current medical monitoring. In the latter event, we are dealing with a typical example of biological control for the purpose of rendering therapeutic care. Orbital space station flights should be one of the important stages in solving the above problems. During such flights, new investigative methods and promising systems of automatic processing and transmission of biomedical data can be tested. No doubt, man's prolonged stay on the orbital stations will furnish valuable scientific information about the mechanisms of regulation of functions in weightlessness. This will allow us to approach more concretely the solution of problems of medical monitoring, diagnostics, and prognosis in interplanetary flight.

Thus, the promising directions of development of methods for physiological and medicobiological measurements in space are related to flights on orbital stations and interplanetary craft. Here we have a wide circle of tasks and problems that require deeper analysis of the experimental material and, on this basis, further development of the methodology of space medicine. There must be continued development of methods of collecting and automatically processing diagnostic and prognostic data. Research in these directions should definitely be directed not only toward solving specific problems of space medicine, but concurrently as well toward development of medicine and public health care on earth.

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FIGURE CAPTIONS

pp 1-2 [85-86]

Figure 1.   Block diagram of the biotelemetry system of Biosatellite 3.
            Legend: 1) experimental data
                    2) 65-channel switchboard
                    3) 65-channel decoder
                 4,5) telemetric transmitters at a frequency of 136.68 mhertz
                    6) coaxial switch
                    7) "diplekser" [duplex?]
                    8) command and telemetry antenna system
                    9) mechanical switch
                   10) biomedical analogue printer-tape recorder
              11,13,14) experimental and engineering data
                   13) time mark

Figure 2.   Block diagram of Vostok 3 telemetry system
              ЭЭГ, ЭOГ) preamplifiers for EEG and electroooculogram recording
                  ЭKГ) amplifier for EKG recording
             Y-1,Y-2) EKG amplifiers used to record EEG and EOG
                  ПГ) amplifier for pneumogram recording
                  КГP) system for recording galvanic skin reactions
                  ЭKФ) electrocardiophone, system for current transmission
                       of pulse rate using the "signal" (C) transmitter
                  AP) autonomous recorder for pulse and respiration
                       rate while landing
                  БP) on-board recorder
                  PTC) radiotelemetry system
                    P) recording device
                    a) preamplifiers
                    b) visual indicator
                    c) recording devices
                    d) audio indicator

Figure 3. Block diagram of Voskhod 1 biotelemetry system

ЭКГ) amplifier for EKG recording

ПГ + СКГ) amplifier for recording seismocardiogram and pneumogram on the same channel

НП) chest belt

УМУ) medical amplifying device to record on the same channel the EEG (ЭЭГ), electrooculogram (ЭОГ), dynamogram (ДМГ), and writing coordination (НП)

БЗУ) on-board memory device

РТС) radiotelemetry system

ПЭК$_\phi$) pneumoelectrocardiophone for transmission of pulse and respiration through the "signal" transmitter

    a) photorecording device
    b) device for visual observation
    c) signal
    d) recording device
    e) audio control
    f) electrodes and sensors

Figure 4. Electrodes and sensors in the Mercury and Gemini programs
    a) improved electrode for EKG recording,
      A) electrode casing
      B) electrode disk
      1) silicone rubber
      2) thin disk of pure silver anodized with silver chloride
      3) "ekonoksid" [?] coating
      4) perforations
      5) wire attachment
      6) outlet wire
    b) placement of electrodes for EKG recording
      1, 2) DS lead electrodes
      3, 4) MX lead electrodes
    c) cuff for arterial pressure measurement
      1) nylon casing
      2) velcro covering
      3) pneumowire of neoprene rubber
    d) design of NASA-Azimuth electrodes installed in the cosmonaut's helmet to record the EEG

1) plastic ring	8) silastic insert
2) silver contact	9) electrode paste
3) silver chloride	10) amplifier's metal contact
4) pressed silver powder	11) outlet wire
5) fire-polished glass disks	12) electrostatic screen
6) acetylcellulose sponge	13) plastic covering
7) rubber ring	14) silastic insulation

Figure 5. Samples of cardiosignals recorded in space flight (ЭКГ, ФКГ, СКГ, ККГ) and under experimental conditions (ВбКГ, ПКГ, X, ЛЭКГ, БКГ)

ЭКГ) electrocardiogram   БКГ) ballistocardiogram
СКГ) seismocardiogram   ПКГ) perimetric cardiogram
ККГ) kinetocardiogram   ВбКГ) vibrocardiogram
  Sa) atrial systole
  Ac) phase of asynchronous contraction
  Is) phase of isometric contraction
  Em) phase of maximum ejection
  Er) phase of reduced ejection
   p) protodiastolic interval
  Ir) phase of isometric relaxation
  Fr) phase of rapid filling
  Dy) phase of slow filling

Figure 6. Block diagram of control system for biochemical automatic device for urinalyses during flight of Biosatellite 3

1, 2, 3, 13, 14) inputs of time marks (1 minute, 5 minutes, 1 hour, 24 hours)
  4) timer (control system of timing sequence of commands)
  5) device for calcium analysis
  6) telemetry on-switch
  7) suction pump
  8) data storage [collection] system
  9) sample collecting command
  10) urine sample control
  11) creatinine analysis device
  12) telemetry output

Figure 7. Results of computer analysis of the EEG. Construction of intensity contours (on the right) and autospectrograms for the first 12 seconds of recording (on the left)

Figure 8. Statistical characteristics of cardiac rhythm with different states of the organism
1) overtension -- stress   4) sleep
2) tension   5) transitional process
3) normal

Figure 9. Spectral analysis of seismocardiogram. Salute 1 orbital station, cosmonaut G.T. Dobrovol'skiy
a) 3rd orbit (first day)
b) 243rd orbit (15th day)
c) 326th orbit (20th day)

Figure 10. Diagram of investigative prognosis in space medicine
        a) levels of organization
        b) areas of prognosis
        c) adverse changes
        d) favorable changes
        e) investigative prognosis
        f) standard prognosis
        g) normal
        h) borderline states
        i) tension
        j) stress
        k) pathological state
        l) scale of states
        m) threshold values of indices
        n) time
        o) information
        p) energy
        q) structure

Figure 11. Dynamics of pulse (1), body temperature (2), and saliva sodium
        (3) in experiment with 64 hours sleep deprivation
        a) background
        b) work
        c) recovery
        d) time of day

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